Utilizing RFID Signaling Scheme for Localization of Stationary Objects and Speed Estimation of Mobile Objects

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Abstract— **Mapping the physical location of nodes within a Wireless Sensor Network (WSN) is critical in many applications such as tracking and environmental sampling. Passive RFID tags pose an interesting solution to localizing nodes because an outside reader, rather than the tag, supplies the power to the tag. Thus, utilizing passive RFID technology allows a localization scheme to not be limited to objects that have wireless communication capability because the technique only requires that the object carries a RFID tag. This paper illustrates a method in which objects can be localized without the need to communicate received signal strength information between the reader and the tagged item. The method matches tag count percentage patterns under different signal attenuation levels to a database of tag count percentages, attenuations and distances from the base station reader.**

I. INTRODUCTION

LOCALIZATION of nodes in a Wireless Sensor Network (WSN) is an important process in the initialization and maintenance of a WSN [1]. Understanding the location of nodes in space allows for the implementation of intelligent algorithms to route data from source to destination with the minimum possible energy consumption and latency while maximizing data throughout. As the precision of node locations increase, more advanced algorithms can be employed to extend the available energy of each node, and consequently the lifetime and coverage of the WSN. However, localization processes that are currently being employed such as ultrasound and lasers, although highly accurate, add size, cost, and a significant power load to the system [2]. This effectively reduces the lifetime of the network by decreasing the energy available to each node for monitoring, generating, and relaying information. Hence, it is necessary to explore novel localization techniques that reduce the energy burden of nodes during the localization phase, and provide more precise localization data.

We believe that passive RFID technology can be employed to perform the localization of nodes in a WSN while incurring little or no energy loss of the individual nodes. Passive RFID tags minimize energy loss because an outside reader, rather than the node, supplies the power to the tag. The RFID system uses backscattering which enables the reader to both power the tag and receive the tag's unique ID [3]. Thus, RFID systems can be utilized to localize nodes by having the RFID reader interrogate the environment of interest for tagged nodes and report if the tag is within the signal range of the reader.

There have been multiple localization methods using RFID technology. SpotON[4] is a well-known location sensing system which utilizes received signal strength indication (RSSI) in RFID technology in order to localize active RFID tags. The SpotON technique is an ad-hoc design which compares the different received signal strength measurements of the active tags to estimate the distance between tags. LANDMARC [5] utilized similar principles to SpotON, and developed an algorithm to reflect the relationship between signal strength and power levels on the LANDMARC system, which did not support RSSI.

Methods for localization of passive RFID tags have been previously proposed based on whether or not the tag is within the interrogation range of a reader. Because the reader has limited range, currently a few meters, these methods estimate the probability that a tag is within a circular disk centered at the reader with a certain radius known from prior calibration measurement. An issue with such technique is false negative reads where a tag is not detected while it is in the range of the reader, and false positive reads where a tag is detected and it is not in the range of the reader [6]. This method provides a rudimentary and inaccurate estimate of the location of the tagged item. Multiple RFID readers can be deployed in the environment and used to each detect the presence or lack thereof of the tagged item in its interrogation disk. The results of such detections can then be combined to provide a more accurate estimation of the location of the tagged item. A time based filter is proposed in [6] to avoid reading false positives and negative reads. This localization technique was expanded to both map an environment and localize the reader in [7] where the FastSLAM (Simultaneous Localization and Mapping) is extended to map a tagged Environment with RFID tags and localize a robot attached to a reader.

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Our goal is to improve the accuracy of the localization in a passive RFID system by utilizing a proportional measurement to that of the received signal strength measurement scheme that was utilized with Active RFID tags in both LANDMARC and SpotOn. Because not all systems include RSSI, like the LANDMARC system, our algorithm characterizes distance between the reader antenna and the tagged item based on the percentage of successful tag interrogations by the reader for different power attenuations. The main distinction between our experiments and both LANDMARC and SpotOn is that we utilize passive tags instead of active tags and that the percentage of tag counts is used as an indication of distance. In our paper we discuss the results from experiments in both stationary and mobile systems. In the stationary system we utilize this algorithm in order to more accurately measure the reader to tag distance. We test our stationary tagged node localization method using a single antenna, off-the-shelf RFID system. In the mobile system we utilize tag count percentages, without attenuation, to examine the ability for RFID to localize and measure the relative speed of the mobile node using tag count percentages.

II. METHODOLOGY

The methodology we employed utilizes a novel tag count procedure to measure the distance between the reader, *r*, and the passive tags, *i*. This procedure determines the percentage of positive tag reads at different tag distances and attenuations. This new localization method is based on the same principles of RSSI that signal strength and tag counts will decrease as a function of both distance and attenuation. However, with the new tag count procedure, localization can occur without needing RSSI.

The passive tags were placed at distinct distances, X_i, from the reader and the signal attenuation localization program instructed the reader to continuously poll surrounding tags in 100 poll steps at differing attenuation levels, *a*, and log both the tag ID and tag count, $T_{a,i}$, of tags within its signal area. This localization program formes characteristic curves for the tags at different distances showing the ability for this tag count procedure to localize objects.

A localization database can be formed from these characteristic curves of the different tags. An unlocalized tag's distance, X_{unk}, can be found by running the signal attenuation localization program and comparing the tag count results, $T_{a,unk}$, to the database with tag counts $T_{a,i}$ using a derivation of Euclidean distance. We first define a vector D_a with length n_t to measure the tag count difference between $T_{a,i}$ and $T_{a,unk}$ at a given attenuation, where n_t is the number of tags and n_r is the number of readers in the environment:

$$D_a = \sqrt{\sum_{r=1}^{\mathrm{nr}} (\mathrm{T}_{\mathrm{r,a,unk}} - \mathrm{T}_{\mathrm{r,a,i}})^2} \qquad (1)$$

The next step is to use D_a to estimate the position of the unknown tag, $X_{a,unk}$:

$$\mathrm{X}_{a,unk} = \sum_{i=0}^{nt} \alpha(\mathrm{x}_{a,i}, \mathrm{y}_{a,i}) \qquad (2)$$

where α is a function that weights the positions of tag *i* differently depending on its relative value in vector D_a (the lower the value the higher the weight).. We then find X_{unk} by summing the weighted positions for $X_{a,unk}$ for all of the attenuations .

$$\mathrm{X}_{unk} = \sum_{a=0}^{na} \chi(X_{a,unk}) \qquad (3)$$

where n_a is the max attenuation and χ is the function that weights each attenuation (χ is dependent on *a*). This equation simplifies in the mobile system because the signal attenuation localization program is altered to not attenuate its power.

III. SYSTEM OVERVIEW

The RFID system utilized in our study was an off the shelf RFID system supplied by Alien Technologies. This system included the 9780 reader equipped with 2 linear and 2 circular antennas. The tags that were used were the ALL-9338-02 "Squiggle" which is a passive RFID tag. The Alien Technologies RFID systems allows the user to monitor the number of reads and control the power of the signal being output through the antenna by attenuating the output signal up to 160dB. Using the Applications Development Kit (ADK) that was provided by Alien Technologies, we developed a java program to implement the signal attenuation localization program described in the methodology section.

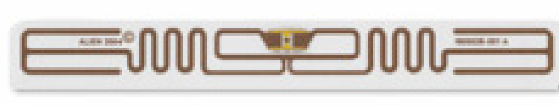

Figure 1. Passive RFID Tag, ALL-9338-02 "Squiggle™"

Initial studies indicated that multi-path effects and metallic objects in close proximity to the reader negatively affect the quality of the tag reads. We minimized these external effects in our experiments by conducting the experiments in open spaces and by removing metallic surfaces from the immediate surroundings of the reader and the tag. Also, given that RFID reads are affected by the surfaces on which they are attached too, all of our experiments were conducted with the tag attached to the same material, namely wood.

IV. STATIONARY RFID TAGS EXPERIMENTS

The initial step to test our method to improve localization within the signal radius of a reader for passive tags was to test our hypotheses in a stationary environment. These hypotheses were: (1) at fixed distances, tag count percentage decreases with attenuation and (2) at fixed attenuations, tag count percentage decreases with distance. In addition we wanted to determine if there was a significant change in tag count for different distance attenuation curves for passive tags. In this section, we conduct single antenna read and single antenna write experiments to explore the feasibility of a localization scheme for passive RFID technology.

A. Single Antenna Read

The primary goal of the single antenna read experiment was to test our two part hypothesis stated above. Second, our goal was to produce characteristic curves of tag reads at different signal attenuation levels and at different distances. These characteristic curves could then be used to localize future RFID tags that are present in the same environment. The experiment was set up by placing a RFID tag directly facing a linear polarized reader at fixed distances from the reader (.5 feet increments from 1 foot to 5 feet). At each fixed distance the reader sends out 100 tag requests at each of the 17 fixed decibels and waits for the tag to reply (10 dB increments from 0dB to 160dB). This procedure was done at three different tag orientations (front, back, and side).

Figure 2. Tag Orientations

B. Single Antenna Write

The goal of the single antenna write experiment was to calculate the difference in distance performance between read and write commands, and to produce decibel write cutoff characteristics for different distances. The experiment was set up similar to the single antenna test with the tag placed directly facing the linear polarized antenna. The reader then sent a write signal, each time attenuating the power of the output signal by increments of 10 dB from 0-160 dB. The RFID tag was placed at a known distance away from the reader and the successful writes to the tag were recorded. This process was repeated for the different distances of the tag from the antenna (from 0.5 to 4 feet with 0.5 feet increments between each run) and for the three different tag orientations (front, back, and side).

V. MOBILE RFID TAG EXPERIMENTS

In addition to localizing nodes that are stationary throughout their lifetime, it may also be necessary to consider localizing mobile nodes. Localizing and tracking these nodes then becomes a more involved and energy expensive process as the localization process will have to be repeated many times, each time depleting the node's limited power supply. Hence, in tracking mobile nodes, there is even more to gain in using RFID technology which does not drain the energy of each node. In this section, we conducted a number of experiments to explore the ability to apply RFID technology to localize and track the speed of a moving object.

A. "Simulated" Movement Localization

The goal of this experiment was to characterize the ability to read mobile tags by moving the RFID tag along a straight line, perpendicular to the reader at fixed distances apart. The motivation for this experiment was to get a good indication regarding the performance of the system in an almost ideal situation. This allowed us to compare the results from the other mobile reader localization experiments. The experiment was set up by placing the tag at known distances in front of the reader (1 foot increments from 1 foot to 6 feet) and moving the tag from 3 feet from the left of the reader to 3 feet right of the reader in 1 foot increments. At each position the reader sent out 100 tag requests at 0 dB, and the tag count responses from the tag were recorded.

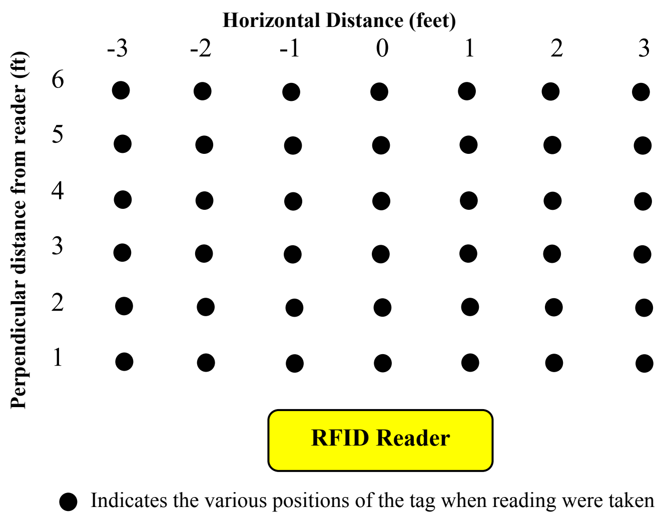

Figure 3. Setup for "Simulated" Movement Localization

B. Mobile Reader Localization

The goal of this experiment was to test the tag counts in a mobile environment. Specifically, we tested if the tag count percentage vs. distance curve obtained when the object is continuously moving corresponds to the similar curve obtained in the "Simulated" Movement experiment.

In this experiment, the reader was attached to a vehicle and moved in parallel to the RFID tag. The tag was then moved back 1.0 foot after every run. This simulates the case where a tagged node is moving away from the reader, as only the relative motion between the reader and tag is important. The reader continuously sent out requests for 100 responses and the tag count responses were recorded.

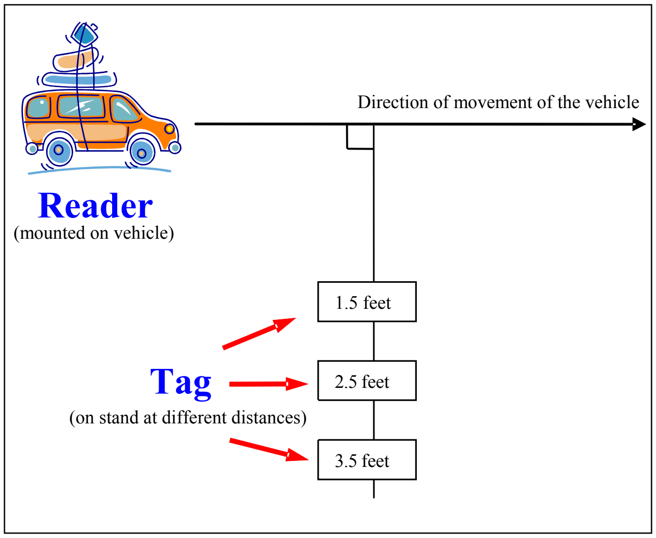

Figure 4. Setup for Mobile Reader at Different Distances

C. *Single Tag Mobile Reader Velocity Estimation*

The goal for this experiment was to investigate if RFID technology can be used to measure velocity of moving objects such as vehicles on the roadway. The intent was to examine if there is a characteristic number of tag reply entries for different speeds of the reader. The experiment was set up with the tag, front orientation, on the side of the road at the same height as the reader. A vehicle with the reader attached to the side drives at discrete speeds (5,10, 20 mph) past the tag. The reader was continuously interrogating the tag at the rate of 5 tag reads per interrogation cycle and the number of successful reads was recorded.

D. *Multiple Tag Mobile Reader Velocity Estimation*

The goal for this experiment was to investigate another method for RFID to be used to measure velocity of moving objects such as vehicles on the roadway. The goal was to see if two tags which were placed at a known distance apart can be utilized to estimate the velocity of the reader. The experiment was set up with two tags, front orientations, on the side of the road at the same height as the reader spaced a known distance apart (50 feet). A vehicle with the reader attached to the side drives at discrete speeds (5,10, 20, 40 mph) past both tags. The reader was continuously sending out requests for 1 response and the tag count responses were recorded.

VI. RESULTS

A. *Single Antenna Read*

The results from the experiment show that localization is possible using passive RFID tags. First, we were able to confirm that tag count percentages decrease with increasing distance from the reader and also with increasing attenuation. Figure 5 illustrates that attenuating the reader's power signal from 0 to 160 dB forms a unique tag count percentage vs. attenuation curve for one-foot increment distances from 1 to 6 feet. Using these characteristic curves, the base station will be able to estimate the physical location of unlocalized tags by fitting the data it receives from the RFID reader to these characteristic curves. We reproduced the experiment five times to ensure that the characteristic curves can be successfully reproduced.

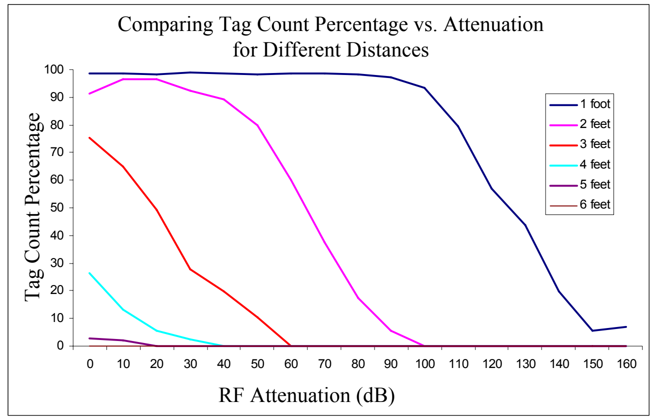

Figure 5. Comparing Tag Count Percentage vs. Attenuation for Different Distances

B. *Single Antenna Write*

The results show that programming the tag behaves similarly to the reading process with respect to changes in distance and attenuation. Although the tag's maximum programmable distance is shorter than the maximum distance it can be read at, the resolution at which the distance can be estimated is increased to .5 feet increments. This occurs as there are distinct attenuation cutoffs for each .5 feet increment that the tag can be programmed at. The minimum attenuation change for programming cutoffs between .5 feet for all three orientations is 20dB. The mode and median attenuation change for programming cutoffs between .5 feet for all three orientations is 30dB. Figure 6 illustrates the programming cutoffs for the passive RFID tags.

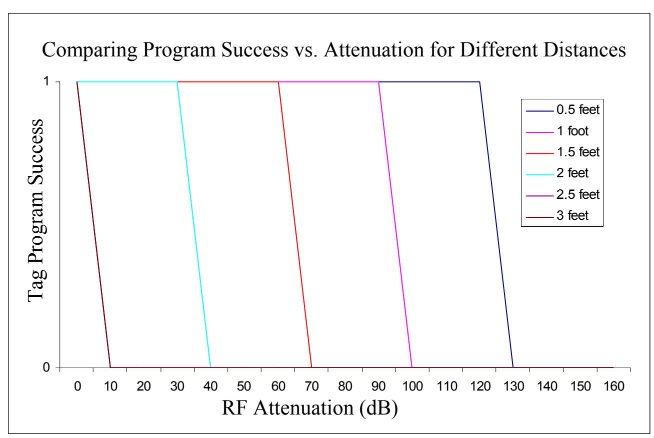

Figure 6. Comparing Program Success vs. Attenuation for Different Distances

C. *"Simulated" Movement Localization*

For the case where we attempt to localize simulated mobile nodes, the results indicate that the closer the tag is to the center of the reader, the greater the difference is in tag count percentages between distances. As the tag approaches three feet to the left or the right of the reader, these differences in tag count percentage between different parallel distances decrease. Figure 7 illustrates that a 3 foot distance gives the most linear drop-off between distance away from reader and tag count drop off. The tag count percentage drop-off rate at 3 feet is approximately 27 per foot with a correlation coefficient of .994, indicating that a linear approximation works very well. Therefore, placing the tag 3 feet from the reader is the optimal position in tracking a mobile object as accuracy drops significantly for distances greater than 3 feet; for distances much less than 3 feet there is a very tight angular window outside of which no reads are detected.

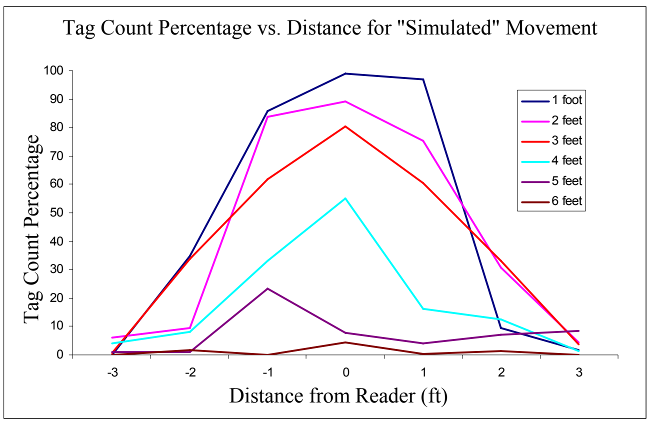

Figure 7. Tag Count Percentage vs. Distance for "Simulated" Movement

D. *Mobile Reader Localization*

Figure 8 illustrates a bell shaped curve for tag count percentage vs. number of interrogations for different tag to reader distances. The highest read count occurred at 1.5 feet and the most number of positive interrogations occurred at 2.5 feet. This is similar to the "simulated" motion experiment where the highest read count occurred at 1 foot and the greatest distance was 3 feet. We compared the results of the two graphs based on the following logic. First, the number of interrogations by the reader is a measure of time steps. Because we ran this experiment in a similar fashion to that of the optimal "Simulated" Movement Localization experiment above, we can therefore assume that the positive reads occurred within three feet from the left of the reader to three feet right of the reader. Therefore the number of interrogations is proportional to distance and the results obtained in this experiment can be compared to that of the "Simulated" Movement Localization experiment.

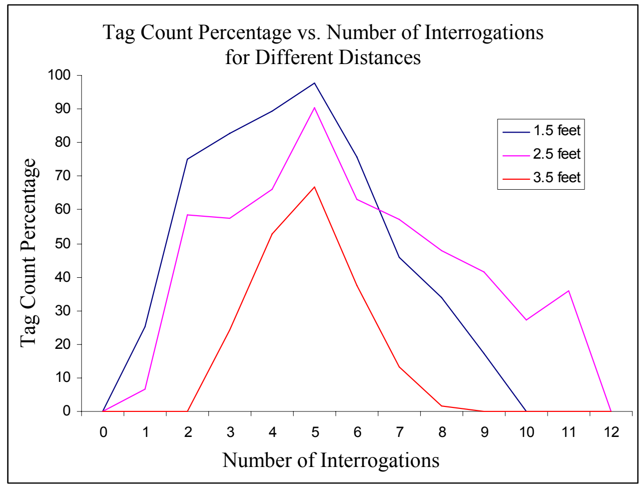

Figure 8. Tag Count Percentage vs. Number of Interrogations for Different Distances

E. *Single Tag Mobile Reader Velocity Estimation*

The results are shown in the Tag Count vs. Speed of Mobile Node graph (Figure 9). Although there does seem to be distinct curves for 5, 10, 20, and 40 mph, not much data can be extrapolated when the vehicle was traveling in excess of 5 miles an hour. Even by setting the max count to 5, there was a max two positive reads when traveling in excess of 10 miles an hour. However, getting one positive is very likely as we never had a complete misread in all 16 runs.

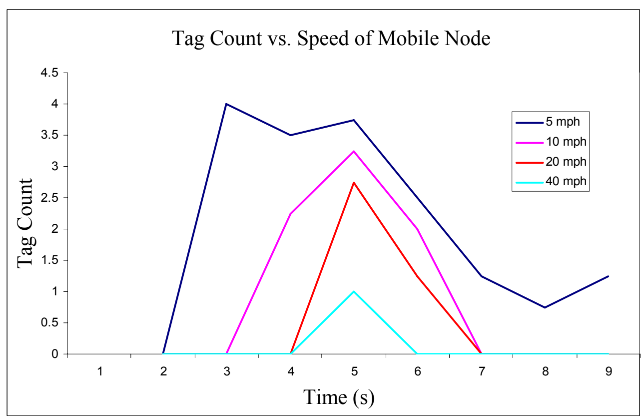

Figure 9. Tag Count vs. Speed of Mobile Node

F. *Multiple Tag Mobile Reader Velocity Estimation*

The results of speed estimation of a mobile node show a strong correlation between estimated speed by the reader to actual speed (Figure 10). The only deviation from the linear relationship between estimated and actual speed is the 5 mph estimate. The inaccuracy of the speedometer and the inability of the driver to keep a constant speed may be the cause of this deviation. These errors are magnified at lower speeds because the deviations from the actual mph are on the same order of magnitude as the desired actual speed.

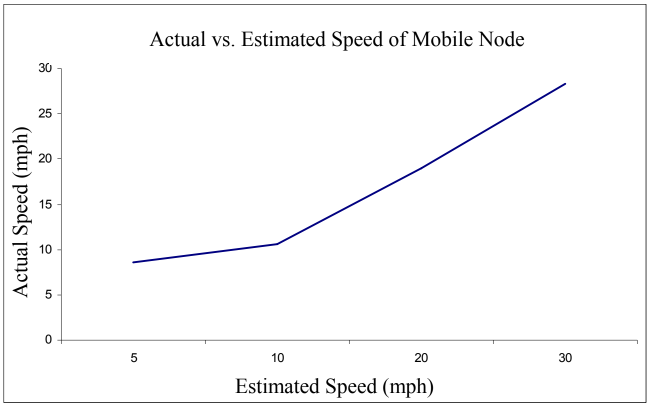

Figure 10. Actual vs. Estimated Speed of Mobile Node

VII. CONCLUSION

From the results presented above, utilizing RFID technology in developing low energy cost methods for localizing stationary nodes and tracking mobile nodes using an algorithm based on tag count percentage is indeed feasible. We have shown that localization of stationary nodes can be performed by first recording the characteristic curves of tag reads under different attenuations at multiple locations in an environment.

In addition to localizing tagged nodes in an environment this database of characteristic curves also minimizes the false positive readings of tags discussed in [1]. The method that we implemented gives tag count percentages for various signal attenuations thus giving a better estimate of the tag's position in the environment. When the property of writing data to a tag is used, the distance a tag is from the reader can be determined with higher accuracy as the write capability of a reader drops off more abruptly than during read cycles, where the drop-off in tag reads are more gradual.

We have also shown that localization and tracking of mobile tags is possible albeit requiring a higher complexity in terms of hardware (we need at least 2 antennas for any localization or speed tracking scheme to work). However, the increased complexity is minimal, as only the base station will need to have substantial amount of new hardware (the RFID reader).

The work in this paper is limited to one-dimensional analysis for localization within a radius of 6 feet. However, with the addition of multiple readers the algorithm can incorporate two and three dimensions.

There are two major directions that this paper leaves to explore. First, the environment can be mapped with a database of characteristic curves at more distances and attenuations to increase the resolution and accuracy of the localization. The second step is to combine localization with an extended writing process. This extended writing process would change the handshaking process from verifying the tag, erasing the tag, and then programming the tag to not requiring a response from the tag to be programmed. This would allow multiple tags to be programmed at the same time with the maximum attenuation from the reader. This extended writing process would both extend the localization distance and allow the tag to be programmed with the value of the distance, proportional to attenuation.

The results presented in this paper indicate the feasibility of WSN and RFID technology merger. WSNs can benefit tremendously from using RFID technology as a low power, secondary wireless communication system. For example, RFID tags can be used as secondary radios to turn on the primary wireless radio in WSN nodes. This would reduce the power consumption of each node as each radio does not need to be periodically turned on to monitor the wireless communication channels for data. In addition, in environmental sensing applications of WSN where nodes store a record of their sensed data for being retrieved by a mobile agent, each RFID tagged node can write sensed data directly to the node. This data can then be retrieved by the mobile agent with an RFID reader on-board.

ACKNOWLEDGMENT

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